A PROTOTYPE CONSTRUCTION OF ADJUSTABLE BICYCLE HANDLEBARS

By

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A Project Submitted in Partial Fulfillment of the Requirements
for the Degree of

MASTER OF SCIENCE

in

Project Management

University of Alaska Anchorage

December 2016

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Table of Contents

List of Exhibits

List of Appendices

Page

Abstract

The riding position of a bicycle is determined by the type of handlebars used. The higher the relationship of the handlebars are to the saddle, the more the rider sits erect and has less stress on the neck, arms and hands. Conversely, the lower the handlebars the more stress forces are felt on those same areas. To manage discomfort and fatigue, the cyclist may stop to rest or sit erect without holding onto the handlebars while still riding. By not holding the handlebars, the rider has little control over steering and no control over braking or changing gears. A solution is to adjust the handlebars from the lower to higher position and still allow access to the hand controls.

This project designed and produced a prototype for compound or adjustable bicycle handlebars. The handlebar assembly provides the rider with the ability to change from a mountain bike posture to that of the more comfortable city and classic bike positions while still retaining complete control of steering, braking, and changing gears. Pending positive results from structural testing, the expectation is that the availability of these handlebars will add to the enjoyment of cycling for a larger audience with diverse cycling needs.

Key Words

Adjustable
Alternate
Articulate
Bicycle
Comfortability
Compound
Configuration
Cyclist
Fatigue
Ergonomic
Extension
Handlebars
Head
Position
Prototype
Stem
Tube

Introduction

Problem Statement

The bicycle is a relatively new device as viewed over the history of humankind. The configuration of the modern bicycle is credited to John Kemp Starley in 1885 with his introduction of the Rover Safety (R. Penn, p. 25). It had a diamond shaped frame, both wheels were the same size, the rider's center of gravity was in the middle of the bicycle, and both feet could touch the ground.

Since that time, the bicycle's popularity has waxed and waned. Currently, the bicycle is popular again for recreation, fitness, and basic transportation. Along with the upsurge of use is the variety of bicycles from which to choose. Bicycles range in price from a few hundred dollars to several thousand dollars. For this reason, it is understandable that the causal user will limit the number of bicycles to a small number, such as one or two. Their choice of style will likely depend on the type of riding that they do the most of the time.

Bicycle riding is a universal activity throughout the world. There are myriad reasons why the bicycle is so widely used, some of which are transportation, work, exercise, recreation, and competitive racing. Each of these areas has their unique attributes, challenges, purposes, functionality and enjoyment. The scope of this paper will focus on one style of bicycle and the challenge of rider comfort.

Riding a bicycle is a purely physical endeavor. As with most physical activity, the better a person's physical condition the better they can enjoy the activity. A person does not need to be in peak physical condition to enjoy bike riding; however, they may find that their endurance to go distances without discomfort and fatigue will be limited. Pain is a major factor in a person's ability to perform most activities—cycling is no different. An elite athlete's muscles are toned to sustain them for extended periods of time without measurable discomfort. But the weekend or occasional rider's muscles are limited in the amount of stress that they can endure before there is noticeable discomfort.

Riding comfort for the occasional riders can be addressed by changing the sitting position on the bicycle. There are four major riding positions that are associated with four differently configured bicycles. The major component that creates these different riding positions are the handlebars (Mission, 2016) (see Exhibit 1). Examples of cyclist using the four riding styles are illustrated with their respective handlebars (see Exhibits 2–5).

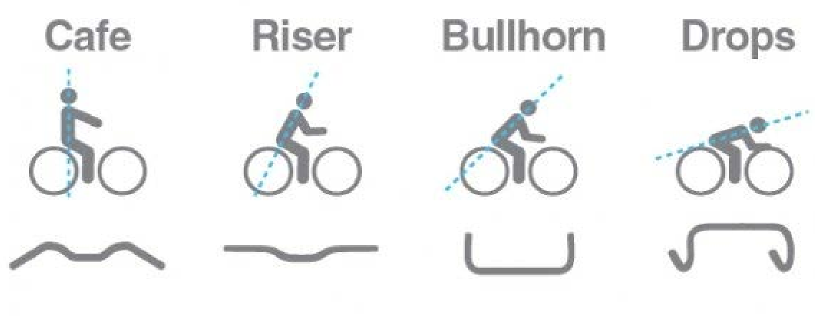


Exhibit 1. Riding Positions and Their Handlebars
Retrieved October 22, 2016 from https://www.missionbicycle.com/blog/do-your-handlebars-fit-your-riding

Exhibit 2. Classic (Dutch) Riding Position and Café Handlebars
Retrieved November 9, 2016 from The Guide to Cycling Ergonomics, Retrieved October 12, 2016 from https://www.missionbicycle.com/blog/do-your-handlebars-fit-your-riding

Exhibit 3. City Riding Position and Riser Handlebars
Retrieved November 9, 2016 from The Guide to Cycling Ergonomics, Retrieved October 12, 2016 from https://www.missionbicycle.com/blog/do-your-handlebars-fit-your-riding

Exhibit 4. Trekking (mountain) Bike Position and Bullhorn Handlebars
Retrieved November 9, 2016 from The Guide to Cycling Ergonomics, Retrieved October 12, 2016 from https://www.missionbicycle.com/blog/do-your-handlebars-fit-your-riding

Exhibit 5. Sporty Bike Position and Drop Handlebars
Retrieved November 9, 2016 from The Guide to Cycling Ergonomics, Retrieved October 12, 2016 from https://www.missionbicycle.com/blog/do-your-handlebars-fit-your-riding

The sporty bike position also uses straight or drop handlebars. Their height placement determines the category in which they belong.

The more adaptable a device is to the human need, the more satisfaction is derived from its use. As an example, the ergonomically adjustable chair that has adjustments for height, lumber support, front and back tilt in general is more desirable by more people than a simple rigid one size fits all.

The design of a bicycle directly effects the posture of the cyclist (Christiaans, H. H. C. M. and Angus Bremner, A., 1998). For the most part, bicycle handlebars are adjusted infrequently and remain fixed after being initially set for the rider. Handlebars are fixed and attached to a stem of limited range to raise or lower their height. By not being able to change the sitting angle while still being able to grasp the handlebars and control the bicycle causes the rider to either stop to rest or not grasp the handlebars. To not control the bicycle by holding on to the handlebars is an unsafe riding practice.

The hypothesis of this project is that bicycle handlebars that have the ability to let the rider change the angle of the torso in relationship to the erectness of their sitting position quickly in the field would reduce fatigue and add comfort to the riding experience. This project focuses three riding positions, classic, city, and trekking. For purposes of this paper the trekking configuration is referred to as the mountain position.

The infrequent rider may enjoy a combination of off road and trail riding in the same outing. The body's angle that the mountain bike handlebars require is well suited for aggressive riding with quick responses while off road. However, when the rider returns to pavement or smooth terrain the position for aggressive riding is no longer desired. Maintaining this position for an extended period of riding and may cause discomfort and fatigue. A solution is to have the ability to change sitting positions and still maintain control of handlebars. The ability to change configurations quickly in the field either while riding or stopping briefly is also a desired attribute.

An example would be a rider using the standard straight style handlebars on a mountain bike. When the rider is experiencing position fatigue the handlebars could quickly be reconfigured to allow for the more erect classic or cruising riding postures. The rider's hands would remain in contact with the handlebars and thereby the brake controls and gear adjustments.

Literature Review

The bicycle is a universal utility vehicle and has many uses as such commerce, recreation, physical therapy, competitive sports, security patrols, and transportation. Given the longevity that the bicycle has been interwoven in society and the number of creative minds adapting it for specific purposes, there may already be a design solution or product on the market that has addressed the problem that this project is focused to solve, namely a system that allows the rider to change riding positions quickly in the field to relieve fatigue and riding discomfort.

A literature review was conducted to identify existing material on the design of handlebars and their relationship to bicycle ergonomics. The University of Alaska Anchorage's (UAA) Consortium Library, the Internet, and bookstores were the primary repositories and sources searched for writings on the subject. The purpose for analyzing the literature was to identify the parameters used to evaluate the recognized ergonomic standards of the bicycle industry. The ergonomic parameters were used as references for distance and angle deltas from standard handlebars for construction of the prototype.

The problem is that the cyclist is experiencing discomfort and fatigue and still has a desire to continue riding. If there are times when the rider is comfortable and not fatigued, why are there times when the rider is not comfortable and is fatigued? Is the latter due to environmental conditions, the condition of the rider, or the condition of the bicycle?

A study of bicycle design concluded that riding comfort is related to the postures required for specific configurations (Balasubramanian, Jagannath, Adalarasu, 2014). Three bicycle designs were used in this study, the rigid frame, the suspension, and the sport. The handlebars for the sport design are lower than the saddle. This gives the riders a lower profile and less aerodynamic drag, however, there is greater downward forces on the back muscles, the neck, arms and hands.

When the test subjects assumed the more erect position of the rigid and suspension configurations, there was less fatigue and discomfort. An analysis of the spine's curvature with relationship to bicycle handlebar configuration identified plausible causes for fatigue (Neuss, 2007). Three areas were the focus of the study, the arms and shoulders, the back muscles, and the crank or pedal area (see Exhibit 6).

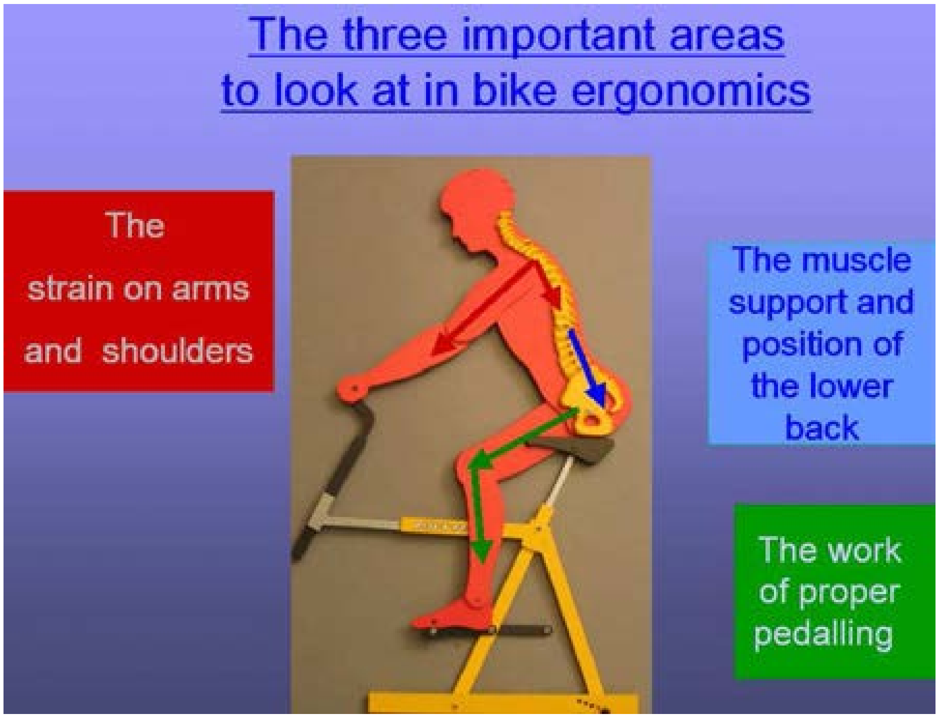


Exhibit 6. Important Ergonomic Areas
Retrieved November 24, 2016 from Bike Ergonomics for All People

The effect of pose "a combination of specific bicycle setup and pedaling technique" identified the previously mentioned three areas of interest—crank length, saddle height, and handlebar position (Korff et al., 2010). The consensus of the articles reviewed is that an evaluation of ergonomic comfort starts with properly fitting the cyclist to the bicycle. The order of sequence to properly adjust the bicycle to the rider is the crank's length and adjustment of the saddle to where the leg is straight when the heel is on the pedal at the crank's lowest position. Next the saddle is adjusted forward or backwards until there is a 90 degree (^{o}) angle between the torso and the arms (Fit Werx, 2015). These three areas were used as a baseline when building, measuring, and evaluating the operation of the prototype and its potential to provide comfort for the rider.

Executive Summary

It is not uncommon to encounter several different types of terrain on a riding outing such as off road, rugged hills, well-worn trails, or pavement. There are bicycles built to accommodate all of these types of terrains, however, it is not practical to carry several bicycles to change out for different surfaces.

Using a style of bicycle that is not made for a certain terrain can lead to unpleasant and possible unsafe riding. For example, a high handlebar configuration may be perfect for city surfaces and riding through urban parks but if the rider comes across an area that is of rugged terrain and decides to take it on, the high center of gravity may cause the rider to fall or ride slowly enough not to fall but by doing so, the thrill of off road riding is diminished.

A solution to not having the correct bicycle for a specific surface is to have the ability to change the rider's center of gravity and thereby reducing discomfort and relieving fatigue. It is proposed that a change in the height of the handlebars will accomplish this.

The purpose of this project was to design a prototype for handlebars that adjust from a low mountain bike position to that of a city or classic upright positions. The operation of the hand controls for applying the brakes and changing gears were to remain in the three positions, low, medium, and high. The transformation had to have the ability to be done quickly in the field with no additional tools.

A prototype was designed and professionally fabricated that had a delta of six inches from the lower position to the higher position. The ability to operate the hand controls remained intact. The next phase is to stress test the prototype for compliance to the safety standards as set forth by the Code of Federal Regulations §1512.6, for the steering system, and §1512.18(g) for the handlebar stem strength. Once the handlebars meet the safety thresholds, surveys that focus on the rider's comfort and demand for this adjustable feature should be administered if the product is to be marketed.

Scope

The scope of this project is to design adjustable handlebars and produce a prototype that will enable the rider to have the ability to change the height of the handlebars in the field. The handlebars will allow the rider to have optimum control for a mountain bike posture while the alternate configuration will allow the rider to change positions to a posture for comfort and still retain the same total control. The project is to stay within 10 percent of the budget (the Expense Budget is located in Appendix A).

Deliverables

This project has two deliverables. If these deliverables meet the criteria outlined in the description, then the project will be deemed successful. The Project Manager is solely responsible for the completion of these deliverables.

1. Deliverable 1 – Drawings of the handlebar assembly that addresses:
    a. Using the main handlebar support stem to change the handlebar elevation.
    b. The position of the adjusted handlebar to the proximity of the rider in the cruiser position.
2. Deliverable 2 – An operational handlebar assembly mounted on a bicycle.

Acceptance Criteria

The following acceptance criteria are required for the project to be considered complete and acceptable to the sponsor. The criteria are as follows:

1. Complete deliverables within 95 percent of the scheduled due dates.
2. Do not exceed the material's budget by more than 10 percent.

Constraints

The following are the time and cost constraints for this project:

1. Materials and vendor costs are not to exceed $4,000.
2. The project must be completed by close of business on December 14, 2016.
3. Any interactions with the public and surveys must be approved by the Institutional Review Board (IRB) and follow IRB guidelines.

Research Methods

The driver for this project is to find a solution for fatigue and discomfort caused from riding a bicycle too long with the handlebars in the same position. To relieve fatigue, riders will either stop and rest or assume a more erect riding posture. Stopping to rest is safe however assuming a more erect sitting position may cause the rider to release control of the handlebars and ride hands free. Riding hands free is common among riders but can be hazardous.

One product was identified, already on the market, that will allow for a change of posture while the rider maintains hand contact with the handlebars. However, this product allows only for a slight adjustment in the handlebar height (Humpert, 2013). Local bicycle shops such as REI, The Bicycle Shop, Off the Chain, online websites that carry bicycle accessories, and the UAA Consortium Library were searched to locate additional products—none were found.

Literature reviews were conducted to discover the fundamentals of bicycle ergonomics that provide comfort to the rider. The reviews not only identified the generally accepted ergonomic parameters for comfort, but also the causes for discomfort. Using data gathered from peer reviewed studies, the possibility of changing from an aggressive style of handlebars to a more casual style seemed plausible.

The scope of this project was to design a working prototype. Using off the shelf products and materials combined with the iterative process of going back and forth from design drawings and physical construction, a working prototype was developed. The prototype's durability and structural integrity as measured using accepted industry standards were not evaluated. Also not evaluated was the public demand for handlebars with a compound function allowing for a change in posture.

Ergonomic Analysis

In general, people learn to ride a bicycle at a young age. After learning to balance, as familiarity increases, confidence and control are quickly developed. As riding a bicycle becomes second nature, little thought or time is given towards gaining more advance knowledge of its operation. Other than possibly a few rudimentary adjustments to the saddle and handlebars, the common practice is for one to merely mount the bike and start riding.

The bicycle has been studied in great detail by enthusiasts, competitive athletes, professional racers, medical researchers, the safety standards industry, and manufacturers (Egaña, Simon, Eoin, Garrigan, and Warmington, 2005). The simplicity of the bicycle's design allows for limited adjustments, in fact three are the accepted norm—the saddle, handlebars, and crank or foot position on the pedal (Stevens, 2006) (see Exhibit 7).

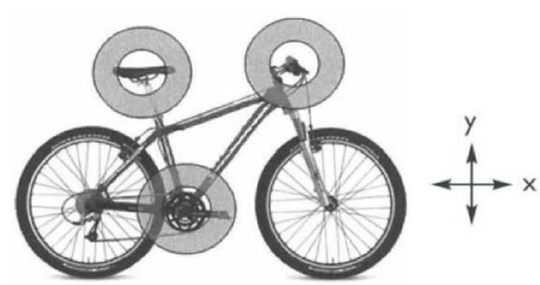


Exhibit 7. The Three Adjustment Points (Stevens, 2006)

The first adjustment is the distance between the saddle and the pedal. The saddle should be adjusted so that when the rider is sitting, the pedal should be at its lowest position on one side of the bicycle. With the heel of the foot on the same side as the lowest position, the saddle is raised until the leg is straight.

Prototype Development

The bicycle is ubiquitous throughout most societies around the world. It is so commonplace that that not much thought is given to its make-up. The fundamental names for the parts that make up the bicycle are generally known—two wheels, a frame, the seat or saddle, pedals, and the handlebars. For the most part, this level of familiarity is sufficient to use a bicycle whether for work or recreation.

However, the bicycle is made up of many components unique to its structural design. As is the case with most machines, as a person's involvement increased so does their need for detail (see Exhibit 8).

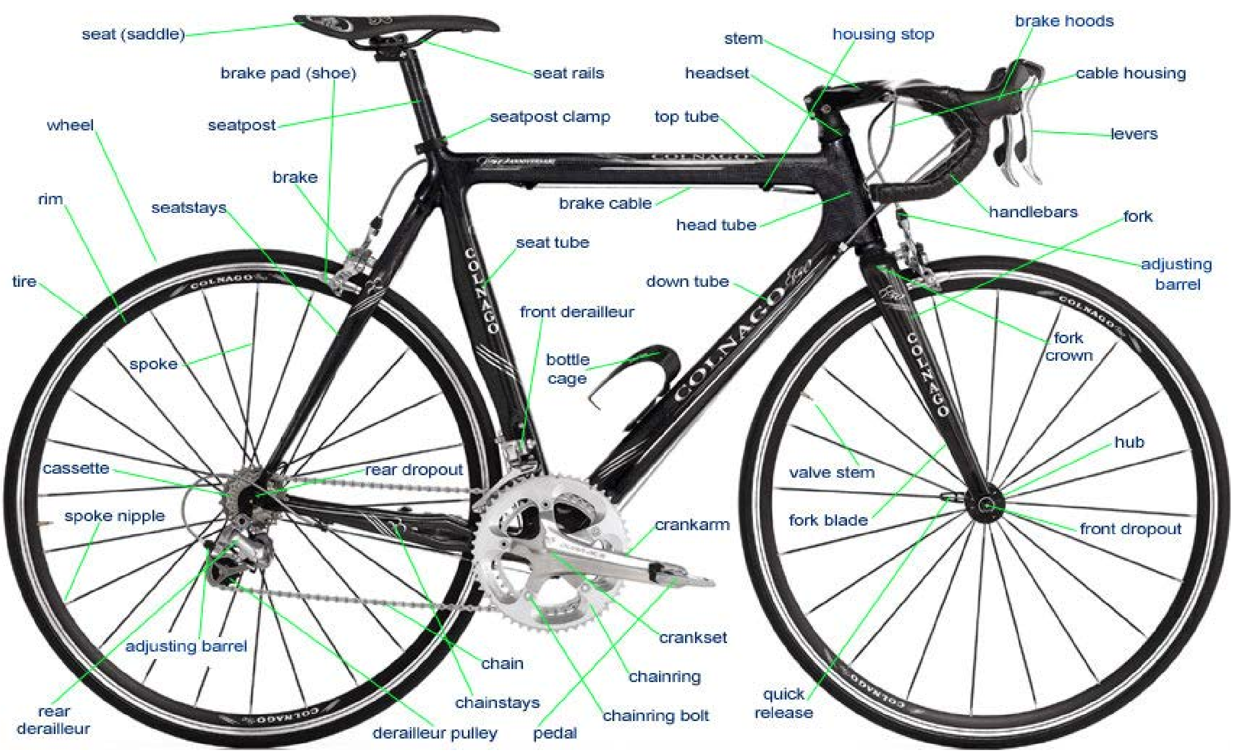


Exhibit 8. In Depth Description of Bicycle Parts
Retrieved October 18, 2016 http://www.jimlangley.net/wrench/bicycleparts.html

The ideas and visualizations of handlebars that would have the ability to morph from one position to another were many. Some had elaborate adjustments that required multiple compound components such as those seen in the transformer robot type toys and movie action superheroes for example the transformation of Optimus Prime from a truck type vehicle to an action hero (see Exhibit 9).

Configuration A | Configuration B

Exhibit 9. Optimus Prime Transformer

Retrieved October 18, 2016 from http://news.tfw2005.com/2016/02/23/spark-toys-war-within-optimus-prime-color-images310403

The practicality of using such an advanced design, while as a concept is appealing, is beyond the objective of this project to be successful. The constraints of the project's delivery time and cost also contributed to the dialing back of the design complexity of the handlebars. The focus changed from multiple adjustments to that of the simplest design to yield a notable change in the rider's position for relieve of fatigue and to give comfort.

Reflecting back to the original observation and perception that the upper body needed to change positons to relieve fatigue and attain comfort, there was a gap between the placements of the hands when in the mountain position verses that of the cruising position. Measuring this distance was not difficult to do but the question arose, "would just extending the handlebars to reach the riders hands be enough?" What about the reach distance from the rider's hands to the handlebars? Would that be too much and the only change would be that instead of being in a low discomfort position the rider was now in a higher discomfort position.

The head tube being used for the prototype is not perpendicular to the ground but is angled back towards the rider (see Exhibit 10). The significance of this backward angle is that the handlebars with be closer to the rider's torso when extended and thereby contributing to a more erect posture.

Exhibit 10. Angled Head Tube
Retrieved October 23, 2016 from http://road.cc/content/news/68971-just-argon-18-gallium-pro

The distance between the positions of the hands in the lower configuration to that of the upper is approximately eight inches using the Project Manager as the test model. Head tubes have unique characteristics and will vary depending on the type of bicycle. The length that the stem can extend is dependent on the length of the head tube minus any constrictions within the neck of the front fork.

Typically, the neck of the head tube is hollow however the inside diameter (ID) is not uniform from top to bottom (see Exhibit 11). The bottom of the neck where it transitions into the fork section has a smaller ID for strength for load support of the bicycle and rider. Also, the adjustable stem has a stop distance a few inches before reaching the end of the stem support collar. The stem needs to stop before it reaches the end of the collar to add stability when extended. Otherwise the torque exerted at the junction of the collar and the end of the stem could increase the chances of failure at that point.

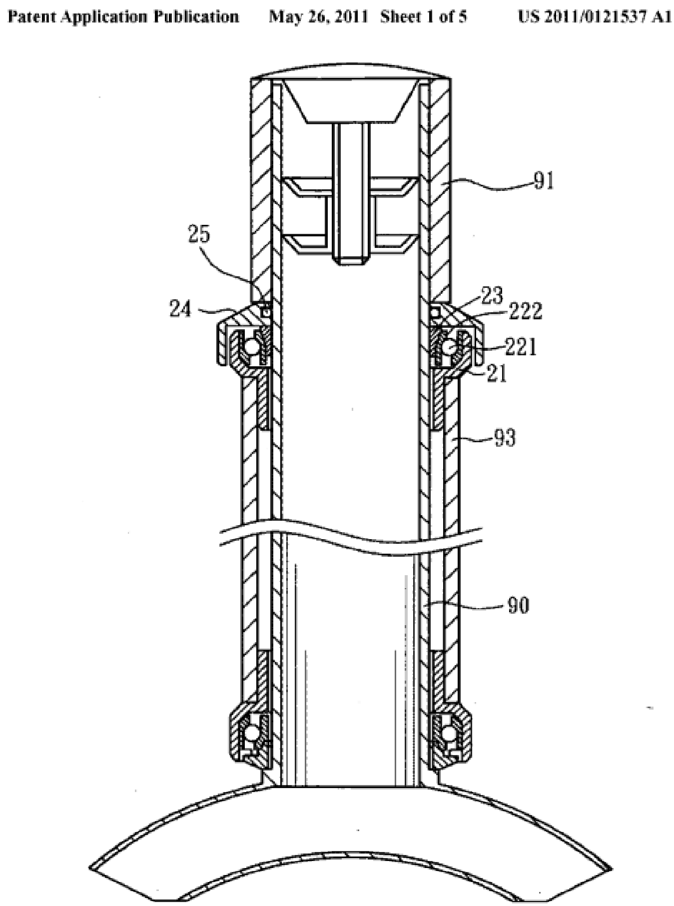


Exhibit 11. Exploded View of Head Tube, Head Set, and Stem Assembly
Retrieved November 4, 2016 from
https://en.wikipedia.org/wiki/Headset_(bicycle_part)#/media/File:Br_threadedheadset.png

Prototype Design

The use of a three-dimensional (3D) printer was initially considered to assist in the design and fabrication of a physical model. However, after further consideration, it was decided not to use one. Some of the challenges identified with using a 3D printer were the following.

Self-use

- The time to learn how to operate the printer
- Learn how to create a 3D file for the printer
- The cost of the printer
- Purchase a 3D printer
- Rent a 3D printer

Vendor services

- Design
- Size of the product
- Time

Conceptually to change the position of the rider, the elevation of the handlebars had to go from point A to point B. How to accomplish this became the challenge. Using two stems of different lengths would be the simplest solution but not the most convenient. Also using two stems would require storage on the bike, carrying tools, and the downtime to change them out. Another option would be to have handlebars with different hand positions—an upper and a lower. In fact, there are many handlebars of this type currently on the market. Product research did not reveal the ability to use the brakes in the alternate hand positions for a commercially available product. A homebuilt solution was identified for the brakes but the gears, also the brakes operated in unison and not independent of each other.

Retaining the use of the hand brakes was one of the original goals. Another set of brakes could be installed for the alternate position however, now additional hardware will be needed such as another set of front and rear brakes or a method of both sets of hand levers controlling the same brake. Using a dual or shared configuration will require more cables, have a cluttered appearance, and design challenges. A simpler method is to use the existing brakes and have a method of repositioning the handlebars from one position to the other. Two possibilities are to have the handlebars pivot from the lower position to the higher one or extend the stem's length to the higher position. Extending the stem was the method chosen based on the following evaluation.

A method to extend the hand positions by altering the handlebars themselves would require using a portion of the handlebars in a vertical configuration for the height and then altering end segments back to horizontal for the hands to grasp. This scenario would result in several pivot points; a minimum of four—two on the right side and two on the left side. Each pivot point or joint creates a point of weakness and lack of stability for the overall structural integrity of the handlebars (see Exhibit 12).

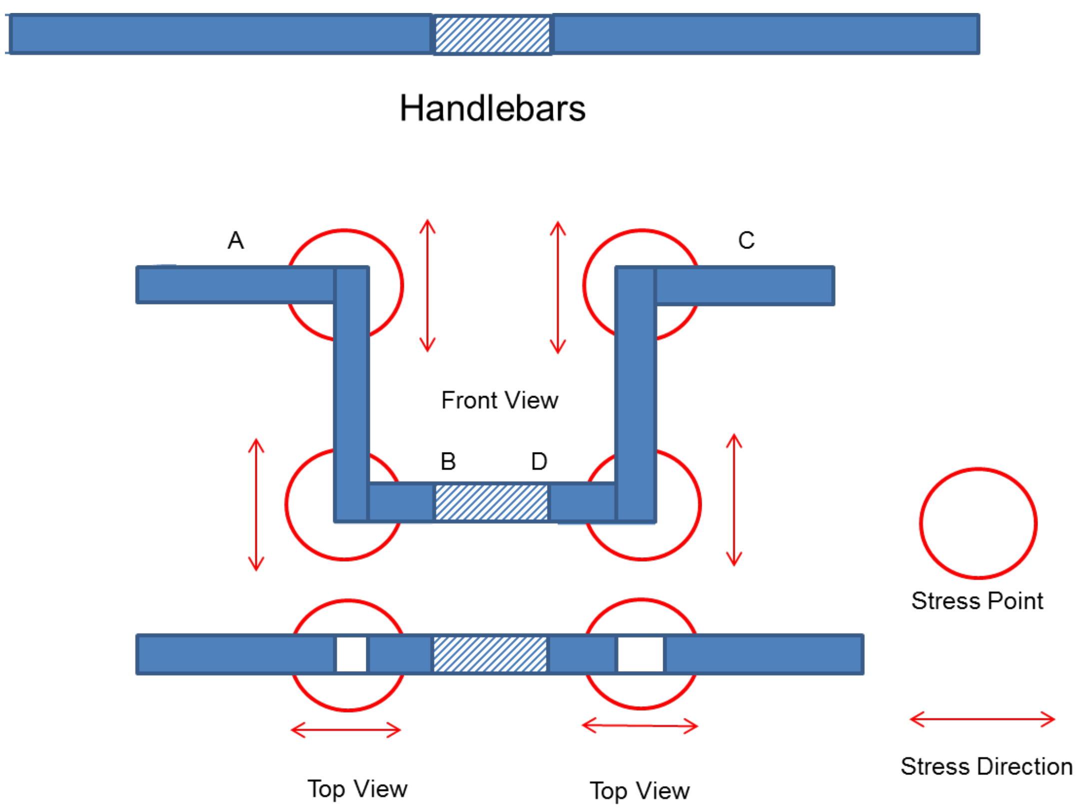


Exhibit 12. Stress Points When the Handlebars Are Articulated

In addition to the forces on the individual stress points, there are additional aggregate stresses from their combined interactions with each other. The difficulty with strengthening the joints is that there must be a measure of free movement to allow for the transformation between configurations. There are design options to counter the negative effects of this design such as providing a connecting bar between points A and C that would counter the downward forces on B and D when the rider exerts downward pressure on the hand positions of A and C.

Not illustrated are the additional frontward and backward forces on all joints but particularly B and D. When the rider pushes or pulls the handlebars to the front or back, the vertical sections between B and A on the left side and D and C on the right side act as levers. This is problematic in that there is torque on the B and D joints similar that of a wrench on a bolt. As the analysis of the transformer configuration identified more structural challenges and the possible remedies to those challenges, the tradeoff between corrective efforts and functional simplicity did not complement each other.

Concept drawings were initially developed as rough hand sketches. These hand drawings along with the prototype were then submitted to be professionally drawn to use for fabrication. The prototype's latching mechanism was part of the commercial product used as foundation material. Due to time constraints, a draftsman was unable to illustrate the latching mechanism on the prototype and suggested an alternate mechanism. The suggestion was accepted for its simplicity. Also, by being different than the one on the prototype, reduced the likelihood of patent issues to address. The original design consisted of a retaining pin controlled by a spring loaded lever to secure the position of the adjustable rod (see Exhibit 13).

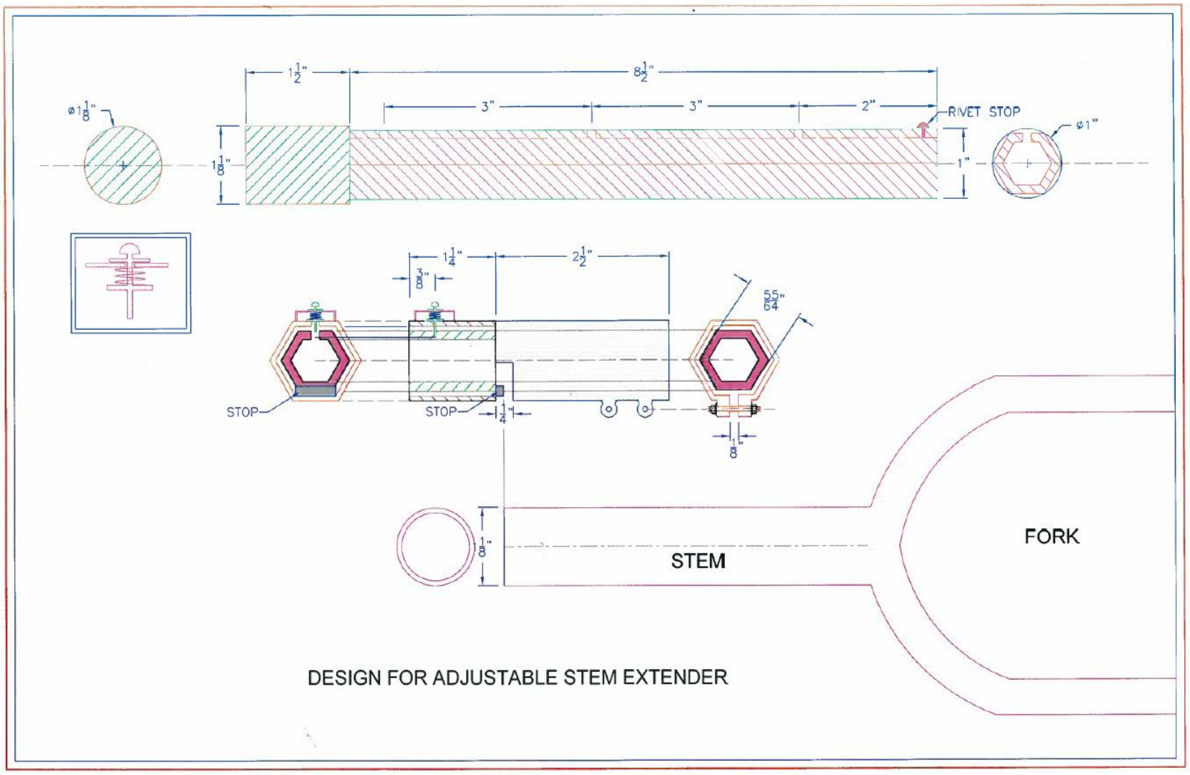


Exhibit 13. Stem and Clamping Latching Assembly

In addition to the latching mechanism, the method for attaching the stem did not seem mechanically sound to the draftsman and an alternate method of using set screws was substituted for what the hand sketches called for (see Exhibit 14). During the construction phase, it was discovered that the first latching option that used a clamping method was valid and subsequently used.

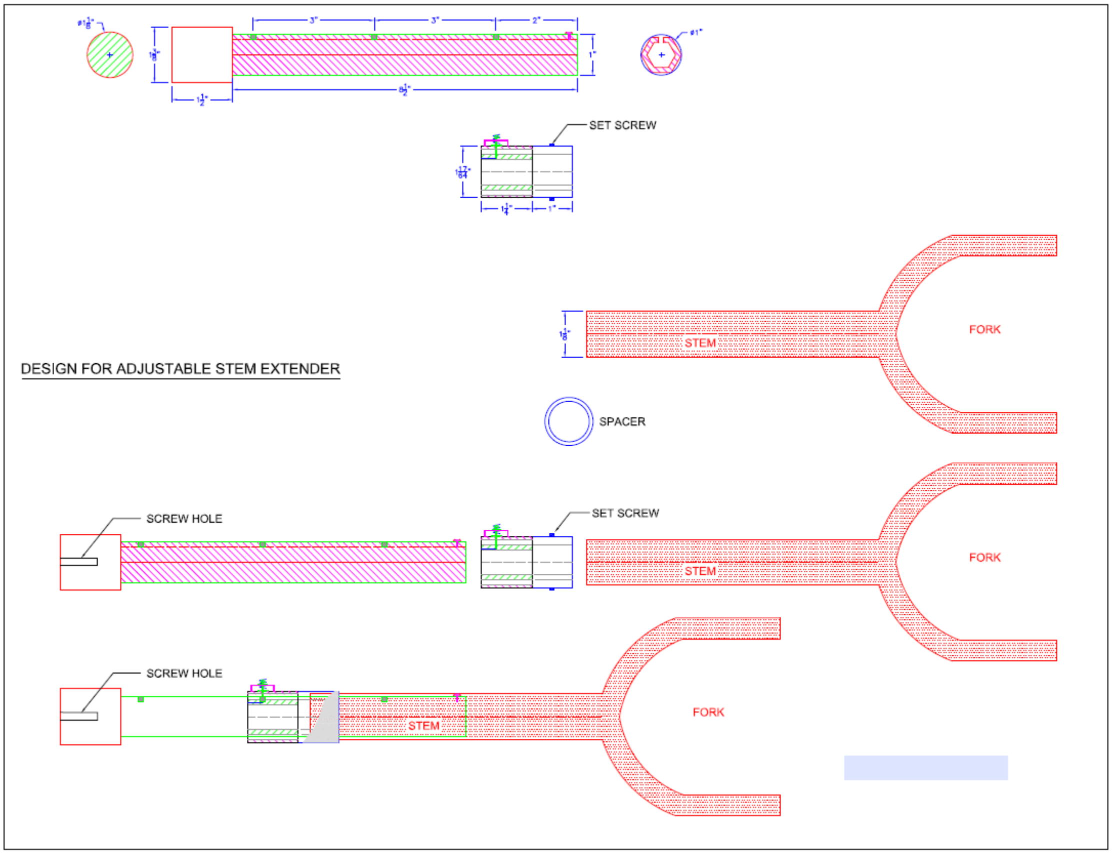


Exhibit 14. Stem and Set Screw Latching Assembly

The solution to change the level of the handlebars by simply increasing the stem length foregoes the problems identified with the transformer configuration with its multiple joints. There are additional stress points inherent with the adjustable stem model, however they are not on the handlebars themselves but are confined to the stem assembly.

The next challenge was to determine how to increase the stem's length to reach the location of the hands when the rider is in a more erect posture. From the field measurements the delta between the minimum and maximum positions is eight inches. The maximum stem length is initially limited to the length of the head tube. The stem cannot extend beyond the lower limit of the head tube without interfering with the operation of the wheel.

The principle of telescoping could possibly be an option to resolve the length restriction of the head tube. This telescoping principle is commonly used with compact hydraulic car jacks. The lifting post of the jack is able to extend several lengths beyond that of the fixed height of the jack through the use of several posts within each other. Not only is the length of the lifting post greatly extended, it also is able to withstand the tremendous weight of a car.

Prototype Construction

The idea of creating compound handlebars included the desire for total creation of the entire prototype from the ground up. The thought was that the product may be worthy of patenting and therefore each component must be different than any other product. However, after assessing all that needed to be done, the constraints of the project, time, cost, availability of materials, procurement of human resources, and administrative duties, led to a different line of thinking. The basic question was what would be unique to the finished product? Was it the function, the design of the mechanism, the material design, etc.? If an inventor's product needed a ball bearing, would the inventor make that ball bearing or acquire it from a vendor and incorporate it into the product? Clearly the latter; which led to a search of commercially available products that could serve as foundational building stock.

The telescoping concept may be a solution; however, the car jack principle uses hydraulic fluid to extend the posts. This would be another level of complexity and challenges to overcome. It was discovered through product research that there are other telescoping mechanisms that do not use hydraulics. One is a method whereby the support post extends from both sides of the locking latch. This telescoping feature is used by some manufacturers in fish landing nets and paint roller extender handles.

This design has features that make it not so favorable to use as a foundation. The latch mechanism alone is relatively long, 5.5 inches. This length presents a problem for cyclists that want to have their handlebars close to the top of the head tube. There are three tubes that make up the telescoping feature—the large stationary main tube (1 $^{1}/_{8}$ inches outside diameter [OD]), the tube between the latch and the main tube ($^{15}/_{16}$ inches OD), and the tube that the latch device attaches to (2 $^{7}/_{32}$ inches OD) (see Exhibit 15). The last tube retracts within the inner tube and therefore has a smaller diameter. This smaller diameter brings into question if the tube has the structural strength to withstand the normal forces and torques exerted upon it by the actions of the rider and those inherent with the operation of the bicycle.

Exhibit 15. Telescoping Handle Assembly

The method for attaching the handlebars to the stem and fork depends on the bicycle's manufacturer. Some makers attach the stem directly to the fork's steerer tube while others attach the handlebars' stem to an insert that fits and locks within the steerer tube. The OD of the steerer tube is 1 $^{5}/_{8}$ inches with an ID of one inch.

The bicycle used for this project attached the stem directly to the steerer tube (see Exhibits 16, 17, 18).

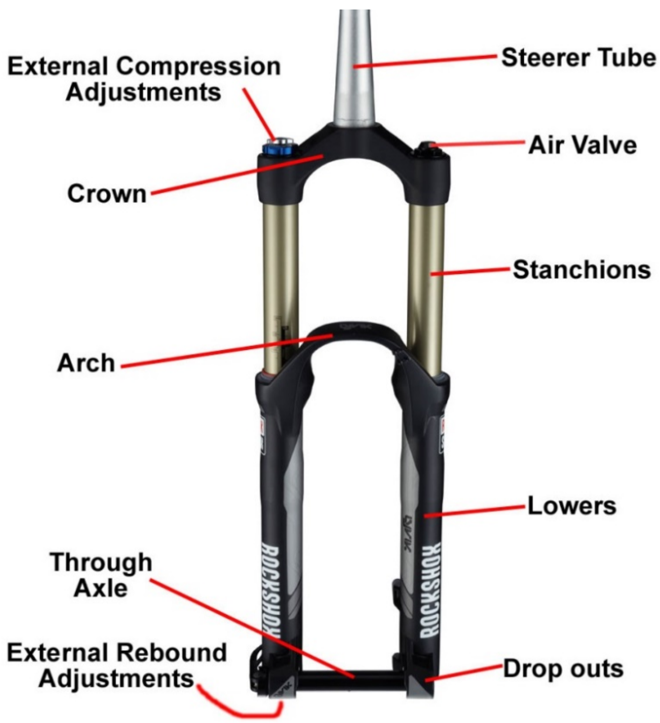


Exhibit 16. Suspension Fork
Retrieved October 23, 2016 from (http://www.bike.bikegremlin.com/2015/12/02/bicycle-fork/)

Exhibit 17. Internal Stem to Steerer Tube

Exhibit 18. External Stem to Steerer Tube
Retrieved October 23, 2016 from (http://road.cc/content/review/169403- specialized-crux-elite-x1)

Another and simpler mechanism is one that telescopes in one direction instead of two as with the previous example. It uses a two tube system with one tube that fits within the other. This extension method is used extensively by many manufacturers for a number of products including that of an expandable paint roller handle (see Exhibit 19).

Exhibit 19. Foundation Material Used for the Prototype

Since there is only one tube that extends, it has a larger OD than the device that extends in two directions. The larger OD is slightly less than the ID of the stem for the handlebars. The length of latch for this design also has a lower profile, 2 $^{3}/_{8}$ inches compared to the previous one of 5.5 inches. As a result of the shorter length, the rider has greater flexibility to adjust to a position that conforms closer to the recommended ergonomic alignment of the rider to the bicycle.

By using this assembly, the steerer tube functions as the outer case leaving two basic parts for the foundation of the prototype—the latch mechanism and the internal stem (see Exhibit 20).

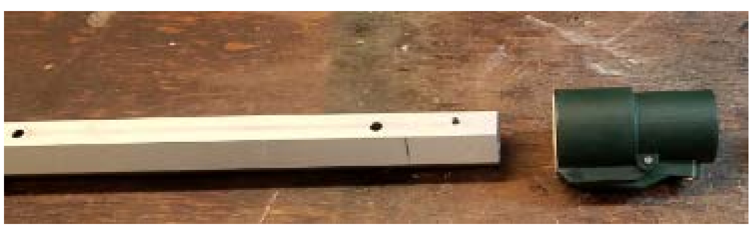


Exhibit 20. Modification of Foundation Material

The stem for the prototype is a hexagon and fits into a round tube—the points of the hexagon are slightly too large and do not allow the tube to fit inside the steerer tube. All six points were filed down to allow the stem to fit within the steerer tube (see Exhibit 21). After OD modification, the stem’s length needed to be trimmed to align with the maximum length of the steer tube, in this case approximately 6.5 inches. The top of the collar is constricted to a hexagon opening. This feature prevents the stem from turning freely within the collar. Once the collar is attached to the steerer tube, the turning force applied by the rider will be transferred to the steerer tube and thereby turn the front wheel (see Exhibit 22).

Exhibit 21. Stem to Steerer Tube

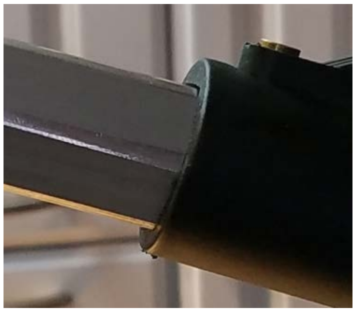


Exhibit 22. Hexagon Stem and Collar

The next challenge was to attach the collar to the steerer tube. The stock material, i.e., the extension handle, is made up of a fiberglass tube, an aluminum hexagon tube, and a semi-hard plastic collar. The original fiberglass tube was cemented into the collar. A fine particulate respirator was used during the removal of fiberglass (see Exhibit 23).

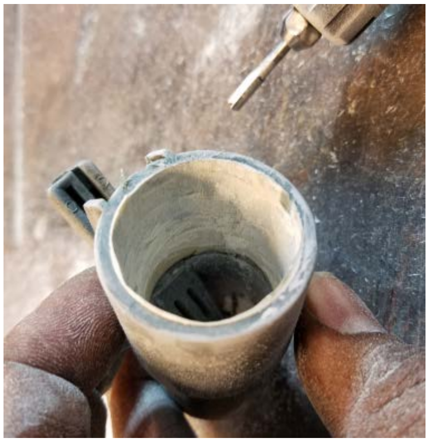


Exhibit 23. Removal of Fiberglass Material from the Collar

The collar of the latching mechanism needed to be removable from the steerer tube instead of being permanently cemented. The primary method to attach bicycle components to each other is by friction fitting. To make a friction fit, a section of the collar was removed and a screw clamp applied (see Exhibit 24).

Exhibit 24. Collar Adjustment to Prevent Binding with the Stem

The movement of the stem in and out of the latching assembly and steerer tube performed as design. However, when the crew clamp tightened the latching assembly to the steerer tube, the stem no longer moved. An analysis of why the stem was being prevented from moving revealed that it was due to the plastic latch becoming unevenly deformed around the stem after tightening of the clamp. A design change was required to prevent the latching assembly from binding the stem. A quick review of the change process using the change management process determined that there would not be a change in the project scope. There would be no additional cost for materials and the time to redesign a solution was negligible.

The conclusion from the analysis of the stem when constricted indicated that as the clamp on the lower part of the latching assembly's collar was tightened, the transition area where the stem entered the steerer tube became distorted. Although the latching assembly's material had the appearance and feel of being rigid, it was plastic and pliable enough to pinch against the stem and stop its movement.

The design task now was for the lower section of the latching assembly to tighten without distorting the upper section thus allowing for the stem's ease of movement and latching. The collar was cut halfway through at the transition between the section that attaches to the steerer tube and the stem holder (see Exhibit 25).

Exhibit 25. Partial Separation of the Latch and Collar Sections

This was done so that when the lower section was clamped to the steerer tube the top section would not be affected and thereby not restrict the movement of the stem. When tested, the stem was not restricted and moved freely in and out of the collar as designed.

The handlebar stem did not fit snuggly onto the adjustable hexagon stem (see Exhibit 26). The hexagon stem was wrapped with strapping tape until the OD increased to where the two pieces fitted snuggly together (see Exhibit 27).

Exhibit 26. Stem to Bike Stem

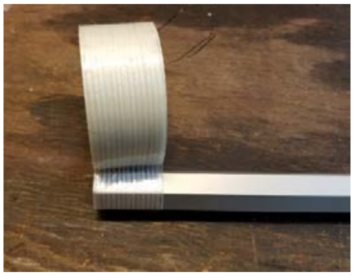
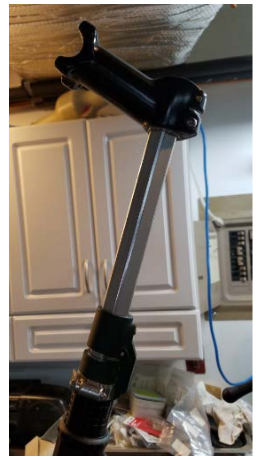


Exhibit 27. Stem Modification

With the two stems connected and clamped to the steerer tube, the adjustable stem performed as designed (see Exhibit 28).

(a) Retracted



(b) Extended

Exhibit 28. Stem Positions

The working prototype, finished drawings, and an off the shelf steerer tube extension were delivered to the fabrication shop. Although the prototype worked as designed when installed on the bicycle, it was never stress-tested for performance in actual use. Of particular concern was the transition between the upper and lower sections of the collar. By cutting the collar halfway through to allow for the lower section to be secured to the steerer tube without binding the stem, there was little remaining material connecting the two sections. When the handlebars were turned, the top section was observed to twist out of alignment with the lower section.

It is reasonable to attribute the weakness of the junction to the type of material that was used to construct the prototype—plastic. Even though the plastic is rigid when used as it was originally intended, it could not maintain its form when subjected to the turning forces exerted upon it by the handlebars.

The problem was addressed by using a commercially available steerer tube extension that is made of thick aluminum and built to withstand the turning forces of the handlebars (see Exhibit 29).

Exhibit 29. Steerer Extension

The fabrication shop identified some potential problems with using the hollow hexagon design for the stem—t would be difficult to fabricate, time consuming, and expensive. A more practical, stronger, and cost efficient solution would be to use a solid piece of aluminum stock with a single flat side.

A single flat side would have to bear all of the turning forces from the handlebars and the suggestion was not accepted. Ultimately, the design was modified to have two flat sides. The turning forces produced by the stem on the latch section are distributed over a wider surface area with the two side configuration (see Exhibit 30).

Exhibit 30. Latch, Top View

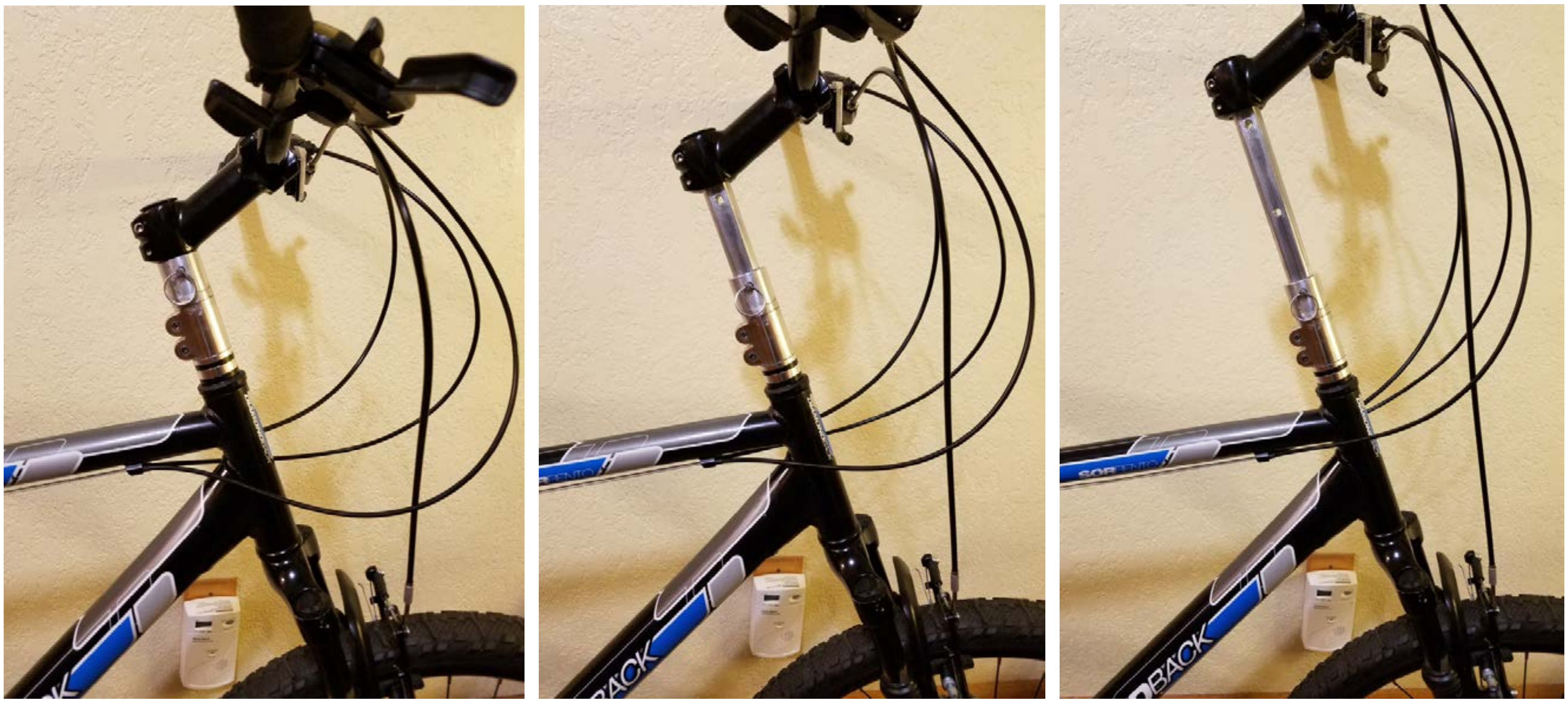
The latching mechanism called for in the design was also not recommended by the fabrication shop due to its complexity. The initial prototype used a single pin on one side to stop the stem's movement. The fabrication shop suggested using a self-retaining hitch or detent pin as a latch (see Exhibit 31a). This suggestion was accepted in that the pin would support the stem on two sides and be made of steel. The finished prototype is made of all aluminum with a zinc coated retaining hitch pin (see Exhibit 31).

(a) Exploded view

(b) Assembled

Exhibit 31. Finished Prototype

When the finished prototype was attached to the steerer tube it would not extended to its highest position; the original control cables were too short. The bicycle was refitted with brake and gear cables that were eight inches longer. Following this modification, the prototype performed as designed (see Exhibits 32A–C).



(a) Retracted (b) Midlevel (c) Extended

Exhibit 32. Stem Positions

Results and Discussion

Time Management

The concept of having the option to raise or lower the handlebars is a simple one at first glance. However, a deep dive into what is required for reliable and safe functionality identified numerous areas and topics to consider. For example, the structural integrity of the material and the design factors could contribute to the device's failure during operation. As more items were identified, it became evident that the scope of the project needed refining to stay within the time allotted for completion. The other concerns identified are certainly valid, however, they would not be included in the scope of this project.

The initial scope was to design three prototypes and select which one to fabricate based on the simplicity of the design. To do so would have been time consuming and more of an exercise in creativity than of use with this project. That is not to say that other designs were not considered, they were and were analyzed for practicality and function but were not developed to a professional drawing.

Functional Analysis

The delta distance between the retracted and extended positions is six inches. The deltas for the angles of the body from the lower to upper positions will be measured once the brake and gear cables have been lengthen to accommodate the extended configuration.

With the cabling in place, data for all three positions of the handlebars was collected to compare with that of previous studies. The top bar between the head tube and the saddle post was used as a horizontal reference for a corresponding right angle triangle consisting of the head tube, the top of the handlebars and the saddle. Using the saddle as the reference point, the acute angle between horizontal side and hypotenuse was measured for each of the stem positions.

A rod was placed between the top of the handlebars and the saddle to represent the hypotenuse to which a cell phone with a level application was used to measure the angles (see Exhibit 33).

Handlebar Position	Handlebar height from Head Tube	Handlebar–Saddle Angle
Low - Mountain	1.25"	4°
Medium - City	4.25"	10°
High - Classic	7.25"	16°

Exhibit 33. Angle Relationship of the Handlebar's Height with Reference to the Saddle

The prototype's three riding positions—mountain, city, and classic—correspond to racing, city, and lady's respectively in a study of body angles (Hsiao, S., Chen, R., Leng, W., 2015). There were six angles measured in the study and five on prototype. There were only two common reference points between the study and the prototype—the hip and knee areas, A4 and A5 from the study, D and E from the prototype (see Exhibits 34 and 35).

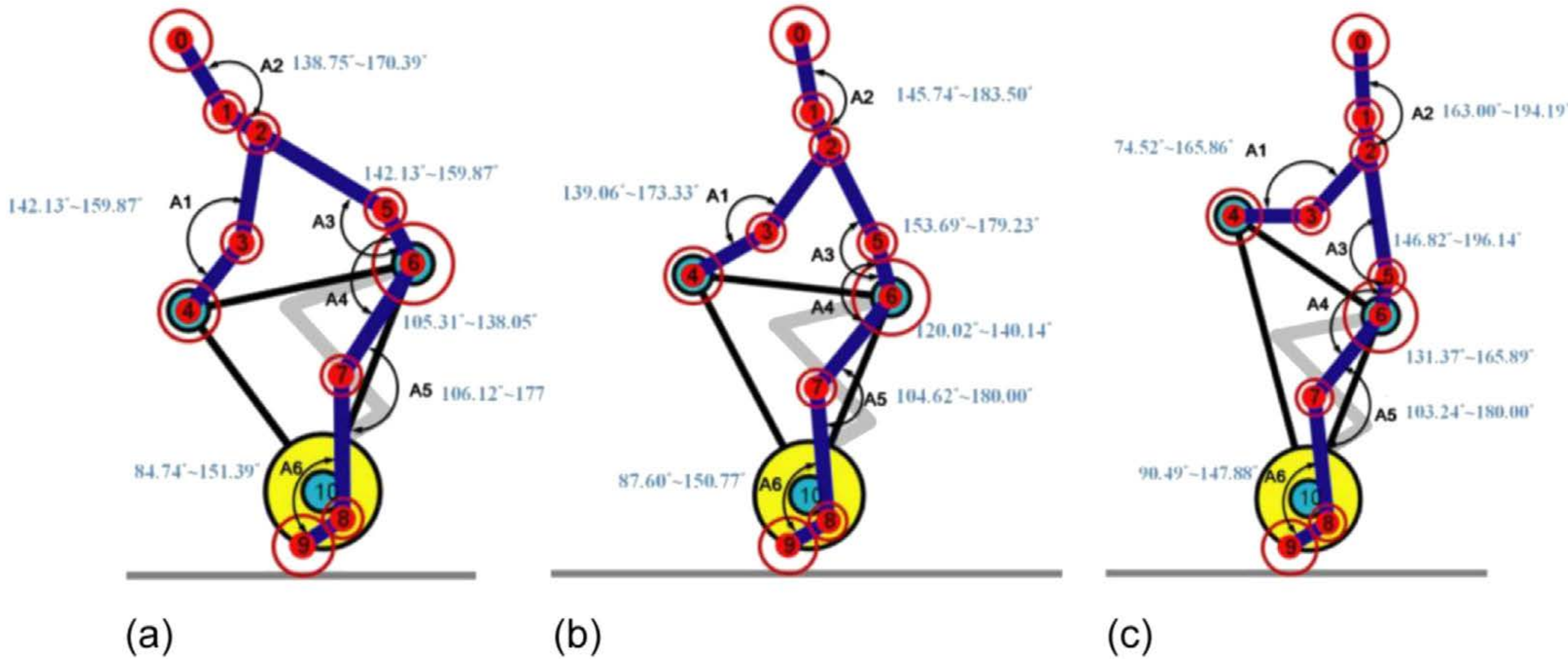


Exhibit 34. Joint Angles on Three Bicycle Types
(a) Racing Bicycle (b) City Bicycle (b) Lady's Bicycle (Hsiao, 2015)

The wrist (a), arm to upper torso (b), and the angle of the spine (c) referenced to a perpendicular vertical line from the saddle were deemed acceptable as alternate areas to analyze (see Exhibit 35).

(a) Mountain (b) City (c) Classic

Exhibit 35. Body Angles for the Three Riding Positions

Data from the prototype and the study showed that there were to common angles. A comparison of these angles revealed that the angles from the prototype were within the range of those reported in the study (see Exhibits 36 and 37). The areas of the elbow (A1), neck (A2), lower torso (A3), and crank (A6) were measured in the study but not on the prototype model due to the complexity of measuring them.

	Angles in Degrees				
	(A)	(B)	(C)	(D)	(E)
Mountain	79	79	22	128	182
City	68	78	17	133	152
Classic	63	80	12	150	156

Exhibit 36. Prototype Joint Angles Matrix for Three Riding Postures

	Research Reference Angles in Degrees					
	(A1)	(A2)	(A3)	(A4)	(A5)	(A6)
Retracted	142.13 - 159.87	138.75 - 170.39	142.13 - 159.87	105.31 - 138.05	106.12 - 177	84.78 - 151.39
Middle	139.06 - 173.33	145.74 - 183.50	153.68 - 179.23	120.02 - 140.14	104.62 - 180	87.60 - 150.77
Extended	74.52 - 165.86	163.00 - 194.19	146.82 - 196.14	131.37 - 165.89	103.24 - 180	90.49 - 147.88

Exhibit 37. Joint Angles Matrix on Three Bicycle Types

(A) Racing Bicycle (B) City Bicycle (C) Lady's Bicycle (Adapted from Hsiao, 2015)

The angles at (E) and (A5) are significant only in that they are within the same range. The change of this angle varies only slightly over the three styles of bicycles. A greater change is observed at angles (D) and (A4). The change of this angle is significant in that it supports the argument that the torso must change relative to the movement of the handlebars rather than the arms.

With a change in the torso the center of gravity also changes which in turns alters the forces on the points of contact between the rider and the bicycle (see Exhibit 38). The change in the handlebar height due to adjusting the stem's length allows the rider to experience one of the three different riding positions—mountain, city, and classic.

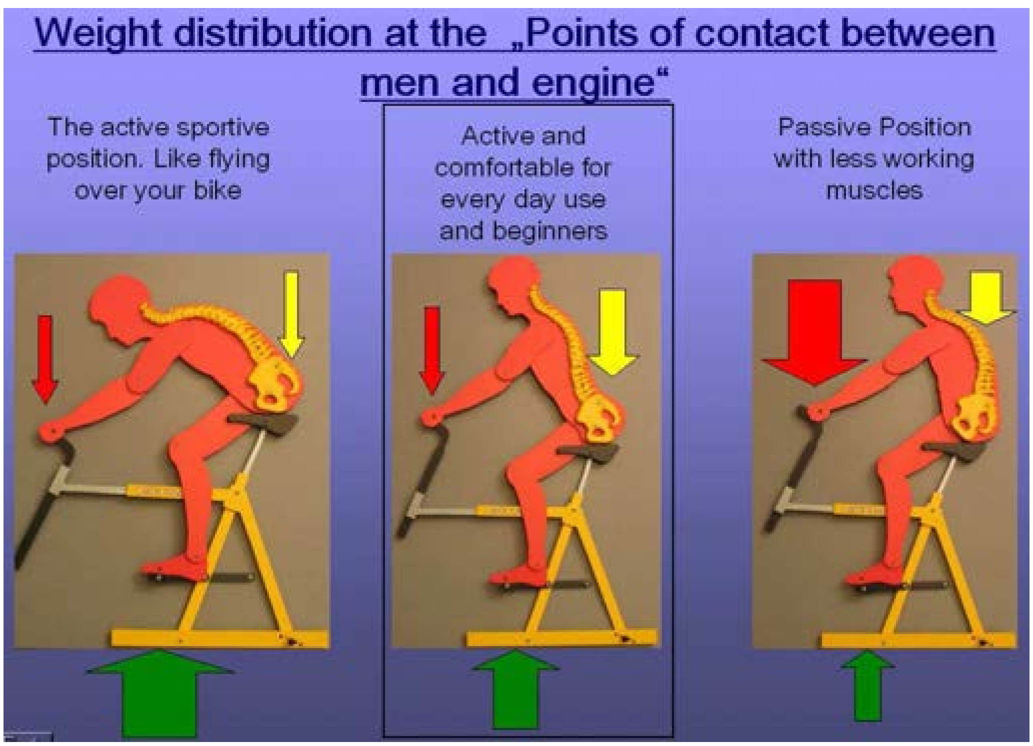


Exhibit 38. Weight Distribution as the Riding Position Changes
Retrieved November 24, 2016 from Bike Ergonomics for All People

Comfort and fatigue cannot be empirically measured. Measurements can be taken and correlated with the subjective feedback from the cyclist but ultimately, the rider is the judge of whether or not a position is comfortable and when fatigue occurs (see Appendix B).

Conclusion

The driver for this project was initiated by one of the immediate stakeholders experiencing discomfort and fatigue of the arms and neck after a brief bicycle outing. An erect sitting position brought relief but created a hazard by riding without holding onto the handlebars. The surface terrain and the rider's ability contributed to the assessment that riding without holding onto the handlebars is a hazard.

Alternatives to solving the problem of sitting erect and losing control of the bicycle were filtered down to two, changing the actual configuration of the handlebars or retaining the configuration but adjusting the length of the handlebars' stem. Altering the stem length was the choice made due to simplicity. Altering the length of the stem mainly focused on the areas of elevation and stability. Whereas changing the configuration of the handlebars involved modeling for elevation, multiple segments, multiple joints, and countering the effects of riding forces.

In collaboration with a drafting professional and fabrication vendor, the final prototype was made from solid aluminum that used a hitch pin to secure the height position of the handlebars. The prototype allows the rider to select three riding positions that simulate those for mountain, city, and classic bicycles. Due to the wide spectrum of rider body types, a rider's comfort level and resistance to fatigue is unique. By offering these three different quick change riding positions on one bicycle, it is anticipated that riders may extend their riding experience with less discomfort and fatigue.

Recommendations

The product of this project, adjustable bicycle handlebars, is intended to allow the operation of the brake and gear changing controls when the rider changes to alternate riding postures. Included in the initial objective was to solve the issue of fatigue and discomfort. The scope of the project was limited to satisfying the needs of one stakeholder. Producing a product for the public at large was not a driver. For that reason, no patent searches, surveys or market studies were performed.

However, as the project progressed, the potential for this product to benefit other stakeholders was recognized. For example, the operation of the adjustable handlebars was intended to be used by the rider during an outdoor outing, however, the location that one operates a bicycle is not the sole factor for discomfort and fatigue. Research on the topic of comfort and discomfort identified a relationship centered on the proper fitting of the rider to the bicycle. Therefore, a cyclist using a stationary bicycle could also benefit from the possible advantages of using adjustable handlebars. A stationary or moving rider can benefit from the attributes of adjustable handlebars whether riding indoors or outdoors.

Other stakeholders that may find a use for adjustable handlebars include persons undergoing physical therapy, have unique physical challenges, have a need or want to change their viewing horizon, adjust to riding with in a group.

To ready the handlebars for availability to the public at large, the previously identified but omitted actions should be executed; they included patent searches, market analysis, surveys, and further comfort testing using human subjects. It was also identified by the fabrication vendor during the production of the prototype that the use of aluminum on aluminum is not the optimum combination of metals to use. The use of a polymer or steel was suggested as an alternative material. Further in-depth testing and analysis need to be performed according to the recognized government safety agencies.

As the prototype's design matures, the opportunity for more advanced latching mechanisms exists. For example, rather than requiring the rider to completely remove the retaining pin and placing it in the next position, a control on the handlebars may disengage and reengage the pin to secure the handlebars height. Another possibility may be to power assist the stem to rise and thus eliminate the need for the rider to pull the handlebars up to the next position. The concept of adjustable handlebars has been shown to be viable and the potential benefits and applications open many areas of opportunities.

Project Closeout

The scope of the project specifies two deliverables, create and deliver drawings for a prototype of adjustable bicycle handlebars and a working prototype. The criteria for acceptance of the deliverables were:

1. Complete deliverable one on or before the scheduled due date.
2. Demonstrate the operation of deliverable two on a working bicycle.
3. Do not exceed the material's budget by more than 10 percent.

The project's complete date is December 12, 2016. Deliverables one, the drawings and deliverable two (see Appendix C), the prototype, were completed and delivered prior to December 12, 2016.

The performance of the prototype after fabrication was demonstrated to the sponsor on November 6, 2016 and to the Master of Science in Project Management department on December 5, 2016. The prototype assembly was mounted to the handlebars of a bicycle and it was demonstrated that that they were able to change from the lower mountain bike position to that of the erect city and classic positions. The deltas between the lower position to the middle city and upper classic position were three and six inches respectively.

The budget for the project was $4,000. The actual cost of materials and fabrication was $1,219 (see Appendix A, Project Budget). The project met the criteria of not exceeding the budget by 10 percent.

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Appendix A

Project Budget

Expense	Estimated Budget	Variance
Labor	$2,400	+/- $240
Internal	$700	+/- $500
External	$1,000	+/- $500
Software	$200	+/- $100
Hardware	$1,000	+/- $500
Insurance	$500	+/- $500
Other	$500	+/- $100
Total	$4,000	+/- $400

Exhibit A-1. Project Budget

Appendix B

Posture and Comfort Exhibits

Average size for three common bicycle frames (mm)

Type	Sex	Distance from the saddle to the ground	Distance from the crank center to the ground	Distance from the handlebar to the ground	Distance from the handlebar to the saddle	Distance from the saddle to the crank center
Racing bicycle	Male (all)	836.00~936.00	250.00	781.62	661.50	244.37
	Female (all)	768.00~908.00	241.87	751.12	653.00	226.37
City bicycle	Male (all)	836.00~936.00	250.00	930.50	620.75	251.50
	Female (all)	768.00~904.00	241.87	902.37	613.00	230.00
Lady's bicycle	Male (all)	836.00~936.00	250.00	1155.75	498.00	248.50
	Female (all)	768.00~908.00	241.87	1104.25	504.62	228.50

Exhibit B-1. Applying Riding-Posture Optimization on Bicycle Frame Design (Hsiao, 2015)

Appendix B (cont'd)

These Handlebars	Totally disagree	•	Disagree somewhat	•	Agree somewhat	•	Totally agree
Fits the hand	1	2	3	4	5	6	7
Is functional	1	2	3	4	5	6	7
Is easy to use	1	2	3	4	5	6	7
Has a good force transmission	1	2	3	4	5	6	7
Are high quality Handlebars	1	2	3	4	5	6	7
Has nice feeling handles	1	2	3	4	5	6	7
Offers a high task performance	1	2	3	4	5	6	7
Provides a high quality product	1	2	3	4	5	6	7
Looks professional	1	2	3	4	5	6	7
Needs low hand grip force	1	2	3	4	5	6	7
Has a good friction between the handles and the hand	1	2	3	4	5	6	7
Causes an inflamed skin on the hand	1	2	3	4	5	6	7
Causes peak pressure on the hand	1	2	3	4	5	6	7
Causes blisters	1	2	3	4	5	6	7
Feels clammy	1	2	3	4	5	6	7
Causes numbness and lack of tactile feeling in the hand	1	2	3	4	5	6	7
Cause cramped muscles	1	2	3	4	5	6	7

Exhibit B-2. Comfort Descriptor

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Appendix C

Drawings

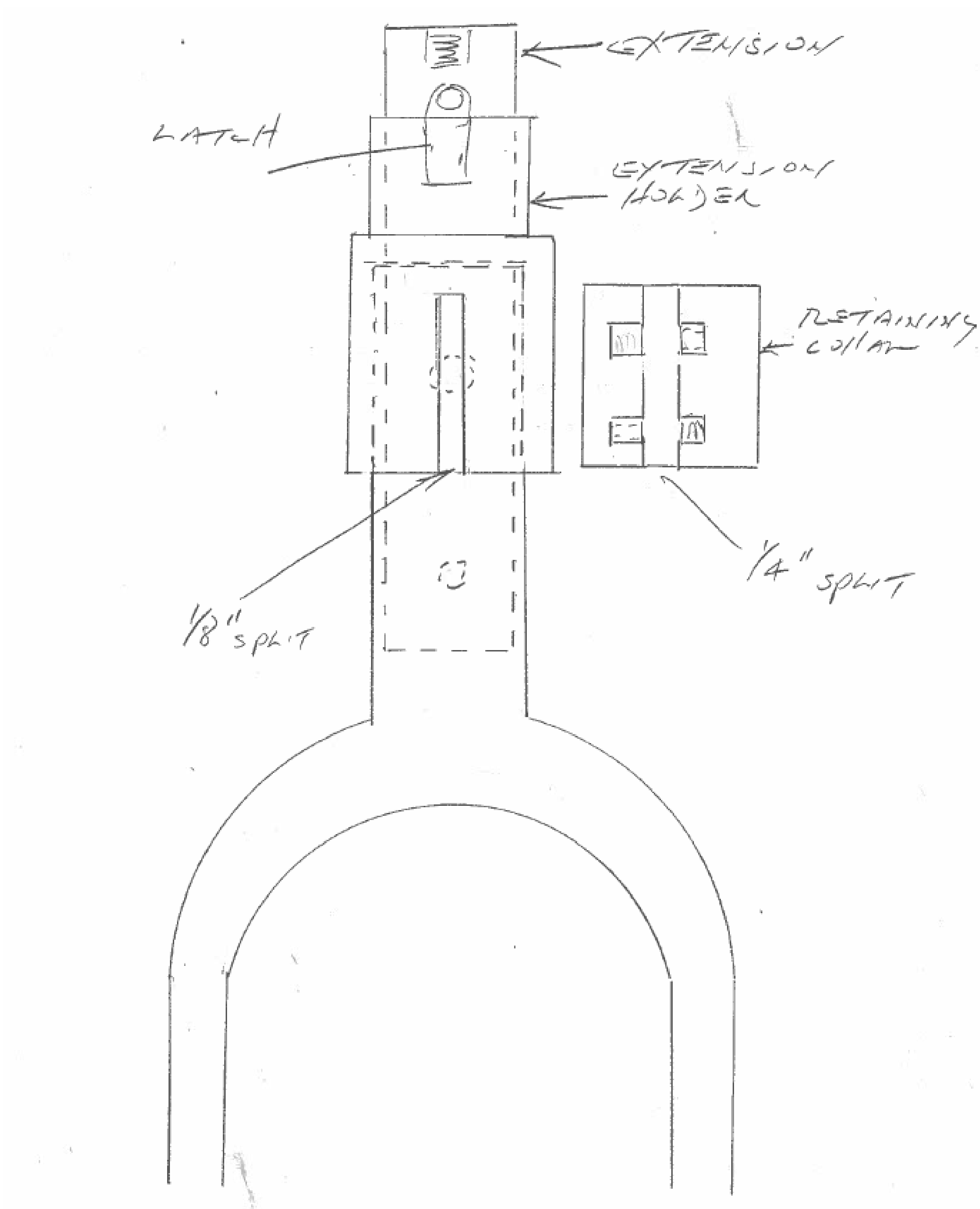

Exhibit C-1. Hand Drawings

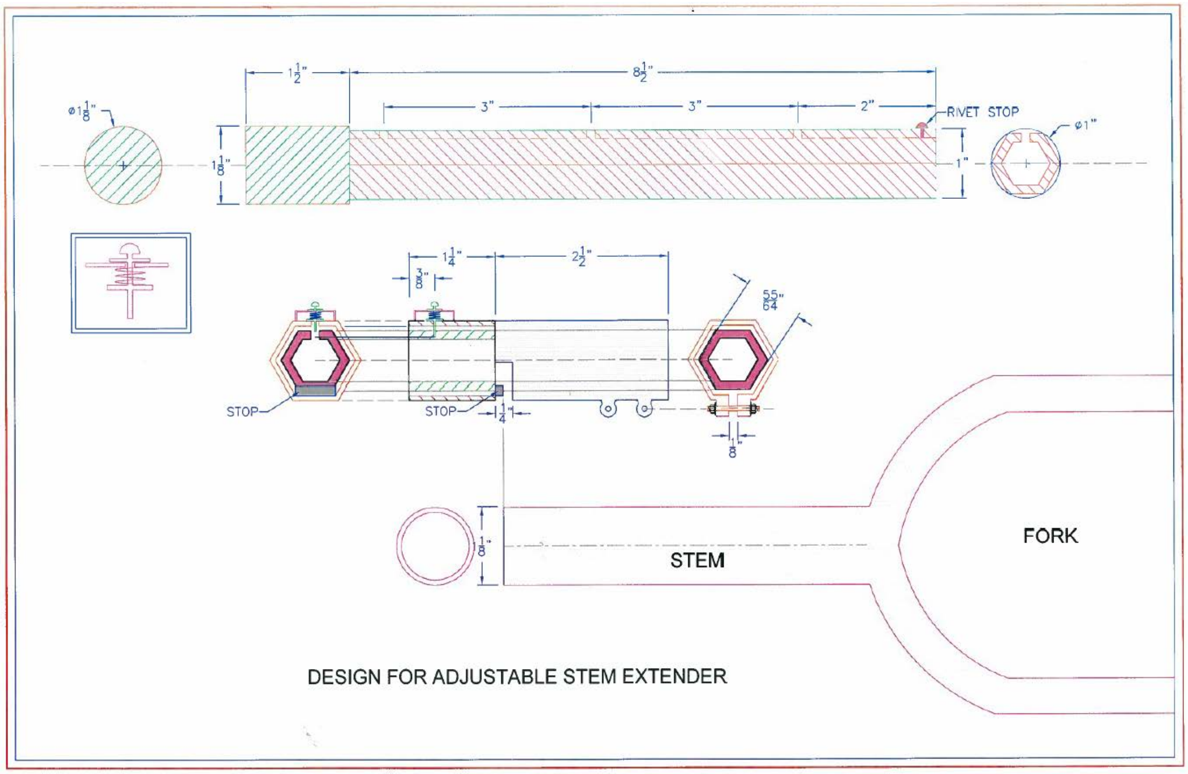

Exhibit C-2. Latch and Clamping Collar

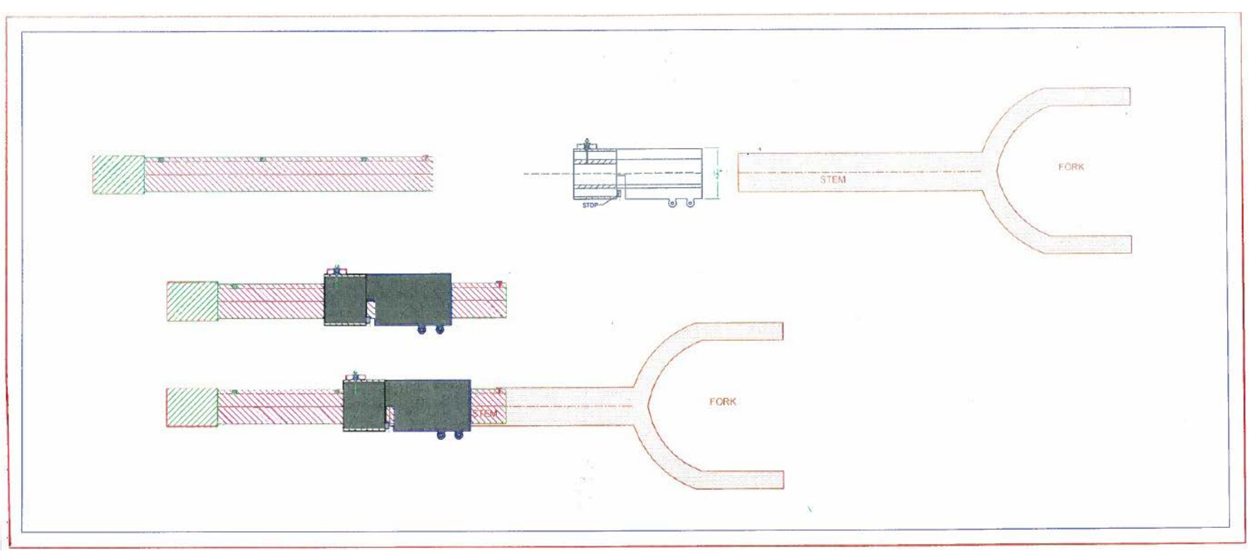

Exhibit C-3. Clamping Collar Attached to Stem

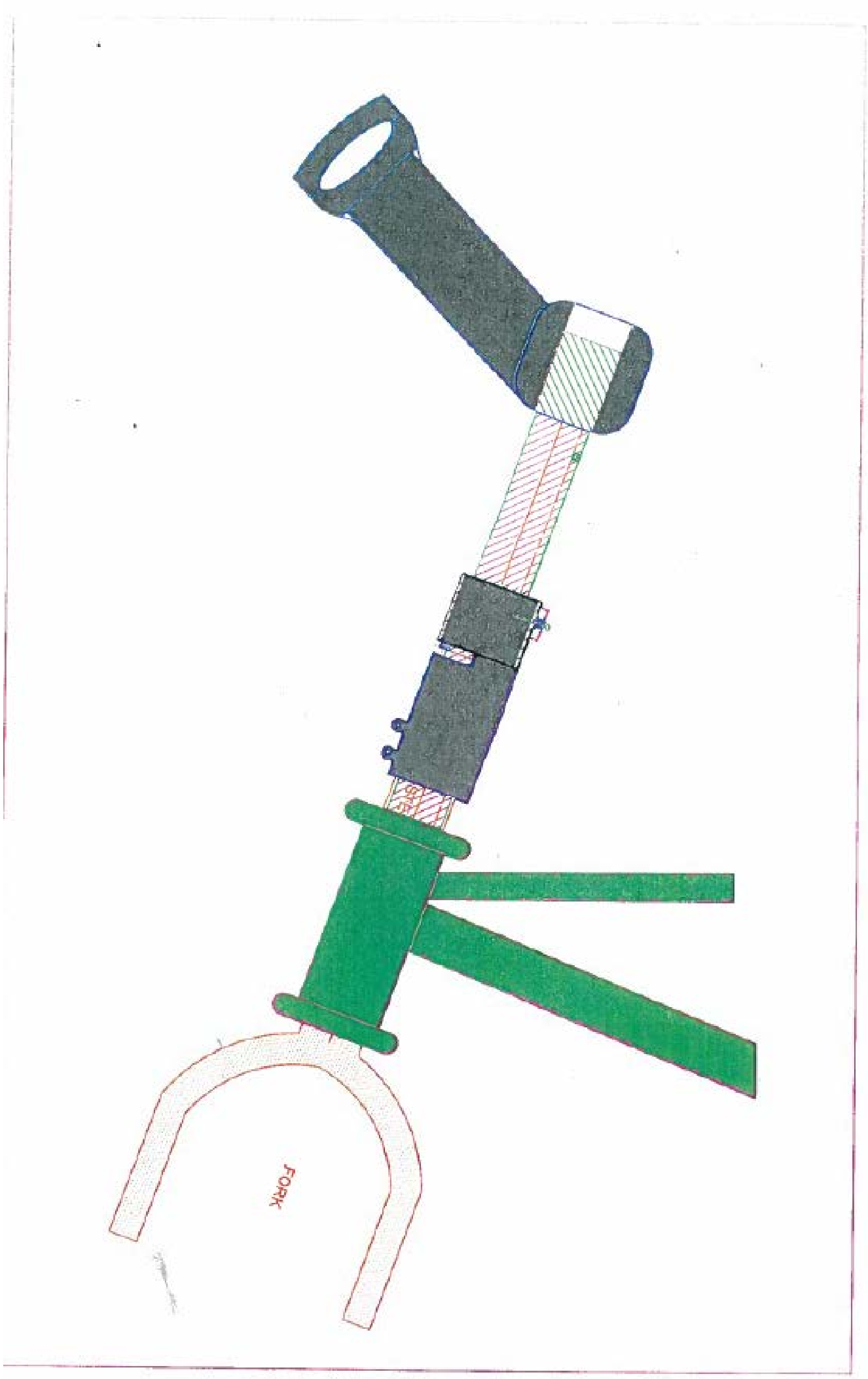

Exhibit C-4. Prototype Clamp Assembly Mounted to Bicycle

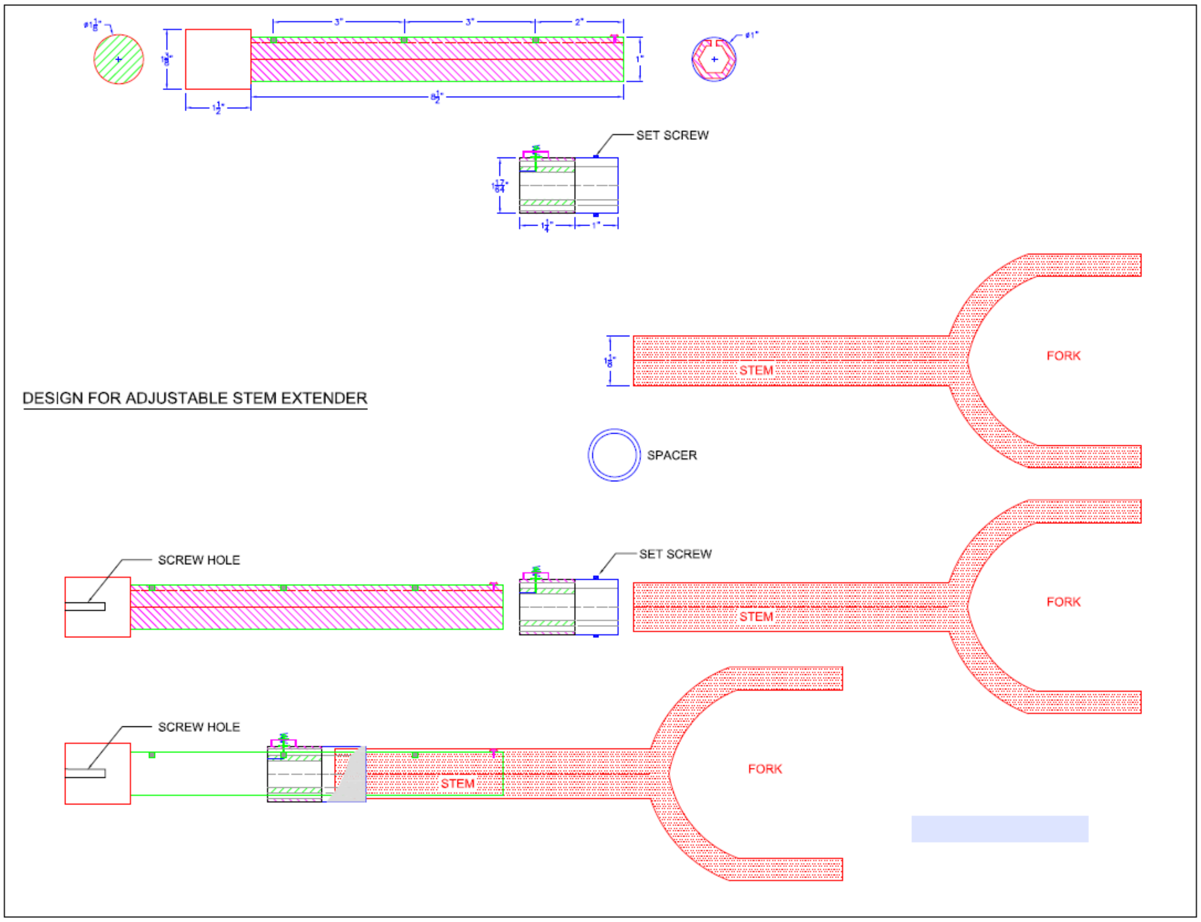

Exhibit C-5. Latch and Set Screws Attached to Stem

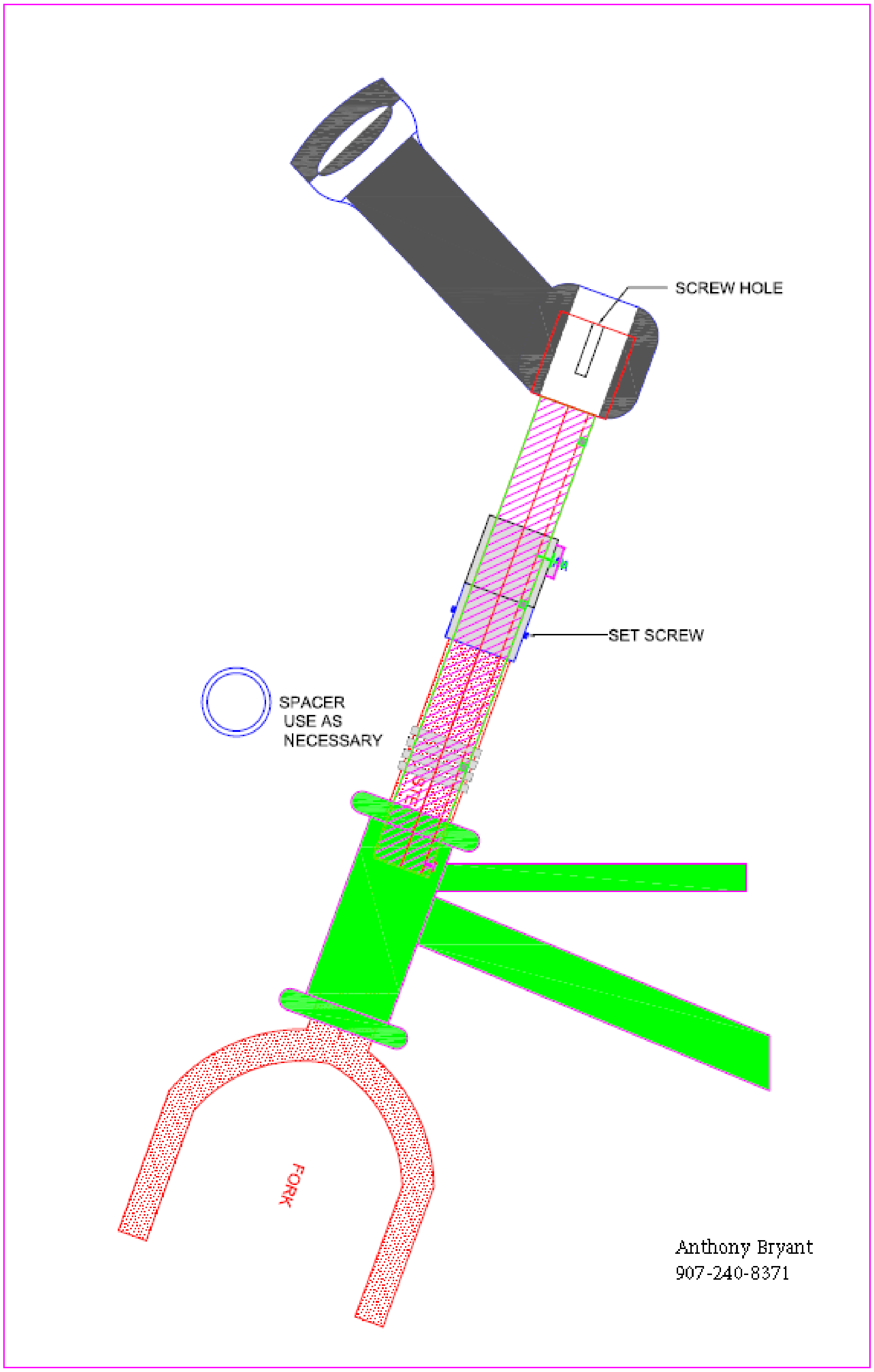

Exhibit C-6. Prototype Set Screw Assembly Mounted to Bicycle